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COMPARISON OF TEST RESULTS FROM A 90^0 SECTOR AND A FULL ANNULUS ADVANCED TURBOJET COMBUSTOR

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SUMMARY

Test results of a 90° sector combustor and a full annular combustor of the same configuration were compared, using separate component test rigs. The combustor investigated was of the double annulus, short length type using the ram-induction concept. It was designed for turbojet engines operating at supersonic flight speeds up to Mach 3.

Measurements in the two rigs of combustor performance including combustion efficiency, pressure loss, exit temperature pattern factor, and exit temperature profile showed good comparisons. Problems of poor circumferential exit-temperature profiles caused by nonuniform airflow in the diffuser occurred in both rigs. Corrections were developed for the 90° sector using a diffuser modification. The same modification applied to the full annulus also corrected the problem. These results proved the value of sector testing in the development of this combustor.

INTRODUCTION

The development of new combustor concepts is usually initiated by testing of sectors of an annulus in place of the full annulus. This reduces hardware costs and allows changes to be made quickly. Also, test facilities can be made smaller and less expensive to operate.

The validity of sector test results for predicting the performance of a full annulus combustor has not been completely established. The step from testing sector hardware to testing the full annulus combustor in a component facility has sometimes been bypassed. Sometimes the combustor concept, if promising from sector test data, has been tested next in a complete turbojet engine. In other cases, results from sector tests have been

applied to full annulus designs but with modifications considered desirable and not tested in a sector configuration.

A test program is currently being conducted at Lewis Research Center and at Pratt & Whitney Aircraft (Contract NAS3-11159) to develop an advanced annular combustor of short length for turbojet engines operating at supersonic flight speeds up to Mach 3. The program includes tests on both a 90° sector and a full annulus. In the course of the program certain configurations have been tested initially in a 90° sector and then in a full annulus. Thus, as a by-product of the program a direct comparison of sector and full annulus results can be made and the validity of sector testing evaluated.

This report presents data comparing results from the two test rigs. Combustor problems solved by hardware configuration changes in the 90° sector were subsequently adopted and tested in the full annular configurations.

COMBUSTOR CONFIGURATION

The combustor being studied (called a twin ram-induction combustor) is shown in cross-section in figure 1. The basic ram-induction concept is discussed in reference 1. The double annulus version used here was initially developed under contract to NASA (ref. 2). The present program is an effort to further improve the combustor and to demonstrate its performance in a full-annulus rig under a range of operating conditions. The 90° sector of this combustor photographed as installed in the diffuser-housing is shown in figure 2. The full annular version photographed without the diffuser is shown in figure 3.

TEST APPARATUS

The test rig for the 90° sector of the twin-ram induction combustor consisted of a small facility having ambient pressure exhaust (15 psia). Airflows for combustion up to 6 pounds per second at inlet temperatures up to 1150° F of vitiated air were used. Outlet temperatures were meas-

ured by a 5 point water-cooled rotating aspirated-thermocouple probe. A photograph of the test rig is shown in figure 4.

The test rig for the full annular combustor consisted of a large closed duct facility having pressure capabilities from below atmospheric to 90 psia. Airflows for combustion up to 110 pounds per second were heated to 1150° F without vitiation before entering the combustor. Outlet temperatures were measured by 3 water cooled probes having 5 points each. The probes rotated within a water-cooled housing with sealed lead-throughs for the temperature and pressure measurements. A photograph of the test rig is shown in figure 5.

RESULTS AND DISCUSSION

Average circumferential outlet temperature profile. - Both the full annular and 90° sector combustors revealed that the average circumferential outlet temperature was affected by the inlet diffuser struts. This is shown in figure 6. A peak in the temperature pattern appears in line with each strut. It was surmised that with a uniform fuel distribution these areas must be deficient in airflow to give high F/A ratios and resulting high temperatures. The air deficiency was assumed to come from the wake effect of the struts. The airflow does not redistribute itself behind the struts possibly because of stalling in the diffuser.

The agreement between the sector and full-annulus data was very good.

Elimination of peaks in average circumferential outlet temperatures. - The above problem was corrected by the use of revised diffuser airflow splitters. The original splitter plates are shown in figure 7. These splitters were designed to direct the air to the outer, center, and inner passages of the combustor and to provide diffusion of the air between their leading and trailing edges. The revised splitter configuration which eliminated the outlet temperature peaks was designed for no diffusion of the air between leading and trailing edges. These splitters were termed airflow spreaders as shown in figure 8.

The revised diffuser configuration using airflow spreaders was first tried and proven in the 90° sector rig. Figure 9 shows no evidence of

temperature peaks behind the struts for tests on the 90° sector.

This successful diffuser airflow revision was subsequently built and tested on the full-annular combustor. The outlet circumferential temperature profile for these tests is also shown in figure 9. Again the temperature peaks associated with the struts were eliminated. Thus, the solution of the problem, obtained on the sector rig, was successfully applied to the full annular combustor.

Average radial outlet temperature profile. - Using the diffuser flow spreader shown in figure 8 in both the 90° sector and full annular combustors, the radial temperature profile measured at the combustor outlet is shown in figure 10. The highest temperature above the overall outlet average occurred at a point about 60 percent of the combustor outlet height for both cases. Also, both combustors showed a drop off of temperatures near the inner and outer walls. The average temperatures are within 25° at each radius where data were taken except at the outer wall. The full annular combustor showed somewhat less drop off (about 70°) at the outer wall than did the 90° sector. Overall, the outlet temperature profiles for the two combustors are quite similar.

Pattern factor. - The values of outlet temperature pattern factor were generally comparable for the 90° sector and full annular combustors. Pattern factor is defined as

$$PF = \frac{\text{Max. outlet temp. - Ave. outlet temp.}}{\text{Ave. outlet temp. - Inlet temp.}}$$

The results obtained before and after correcting the diffuser with airflow spreaders in both rigs is given in the table below.

	Diffuser Correction	
	Before	After
90° sector	0.27	0.22
Full annular	0.37	0.26

The comparison was better after correcting the diffuser than before. The difference in pattern factor of 0.04 between the two test rigs after correcting the diffuser is within the variation that occurs between successive builds of the same combustor.

Pressure loss. - The combustor pressure loss measured the same for the 90° sector as for the full annular combustor. The data for both combustor tests are shown in figure 11 for a range of diffuser inlet Mach numbers.

Combustion efficiency. - The 90° sector and full-annular combustor efficiency measurements were in agreement and ranged from 96 to 100 percent at 15 psia. These data at low pressures were slightly below the efficiency at 90 psia for the full-annular combustor which measured 100 percent. The slightly lower combustion efficiency was probably due to the lower pressure. This trend as shown in figure 12, appears consistent with operation of a ram-induction combustor tested previously.

CONCLUSIONS

Test results of a full annular combustor in a component rig were compared to results from tests of a 90° sector of the same configuration. The following results were obtained.

1. Combustion efficiency, pressure loss, exit temperature pattern factor, and exit temperature profiles compared well in the two test rigs.

2. Problems of nonuniform airflow in the diffuser were found in both test rigs. Corrections that were developed for the 90° sector were applied successfully to the full annular combustor.

REFERENCES

1. Chamberlain, John: The Ram Induction Combustor Concept. Presented to the AIAA Third Propulsion Joint Specialist Conference, Washington, D. C., July 18, 1967.

2. Kitts, D. L.: Development of Short-Length Turbojet Combustor. NASA CR-54560, 1968.

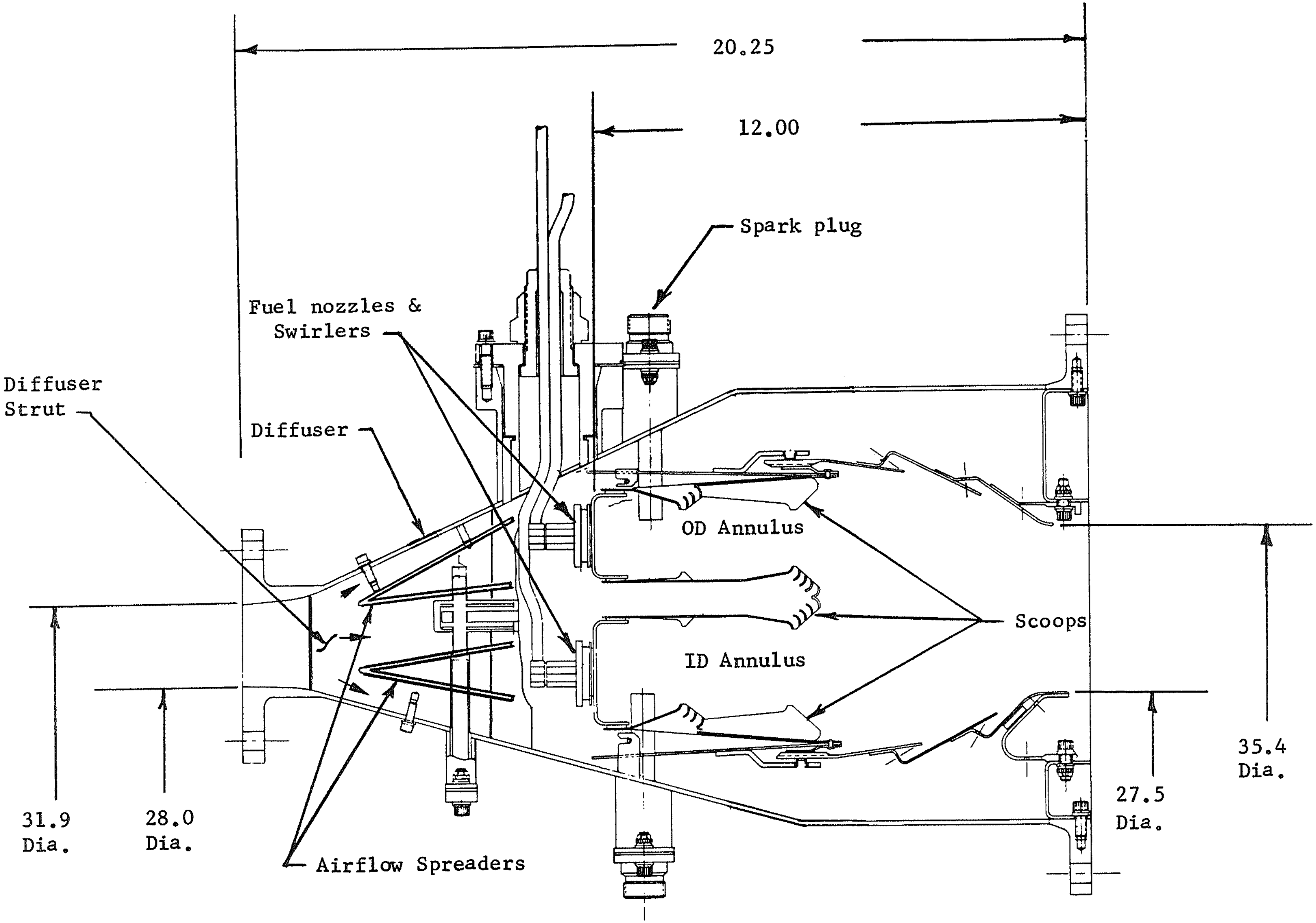

Figure 1 .- Cross-Section of Twin Ram-Induction Combustor. Dimensions in Inches.

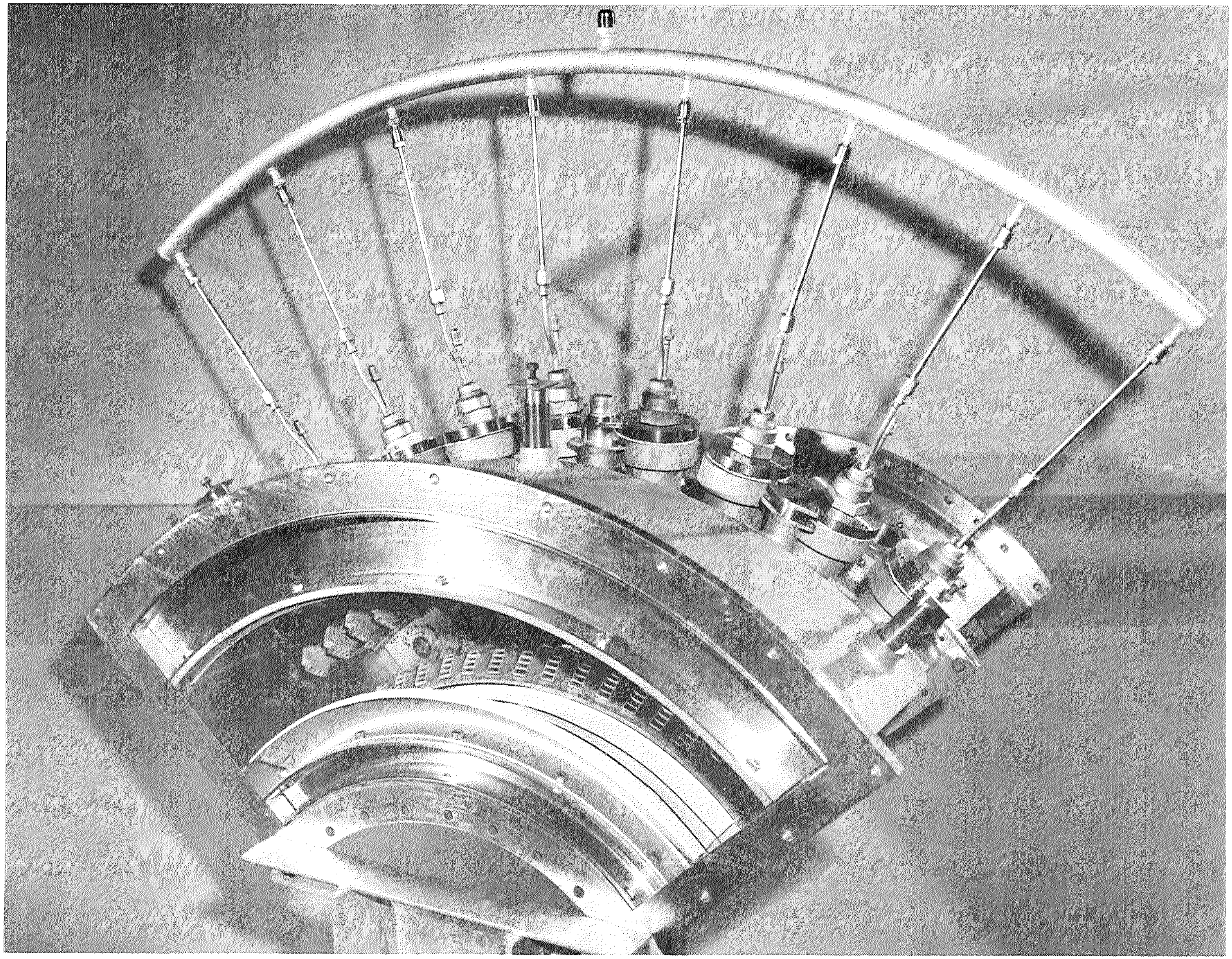

Figure 2. - 90° Sector of Twin Ram-Induction Combustor. Viewed from Downstream.

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Figure 3. - Full Annular Twin Ram-Induction Combustor
Viewed from Downstream

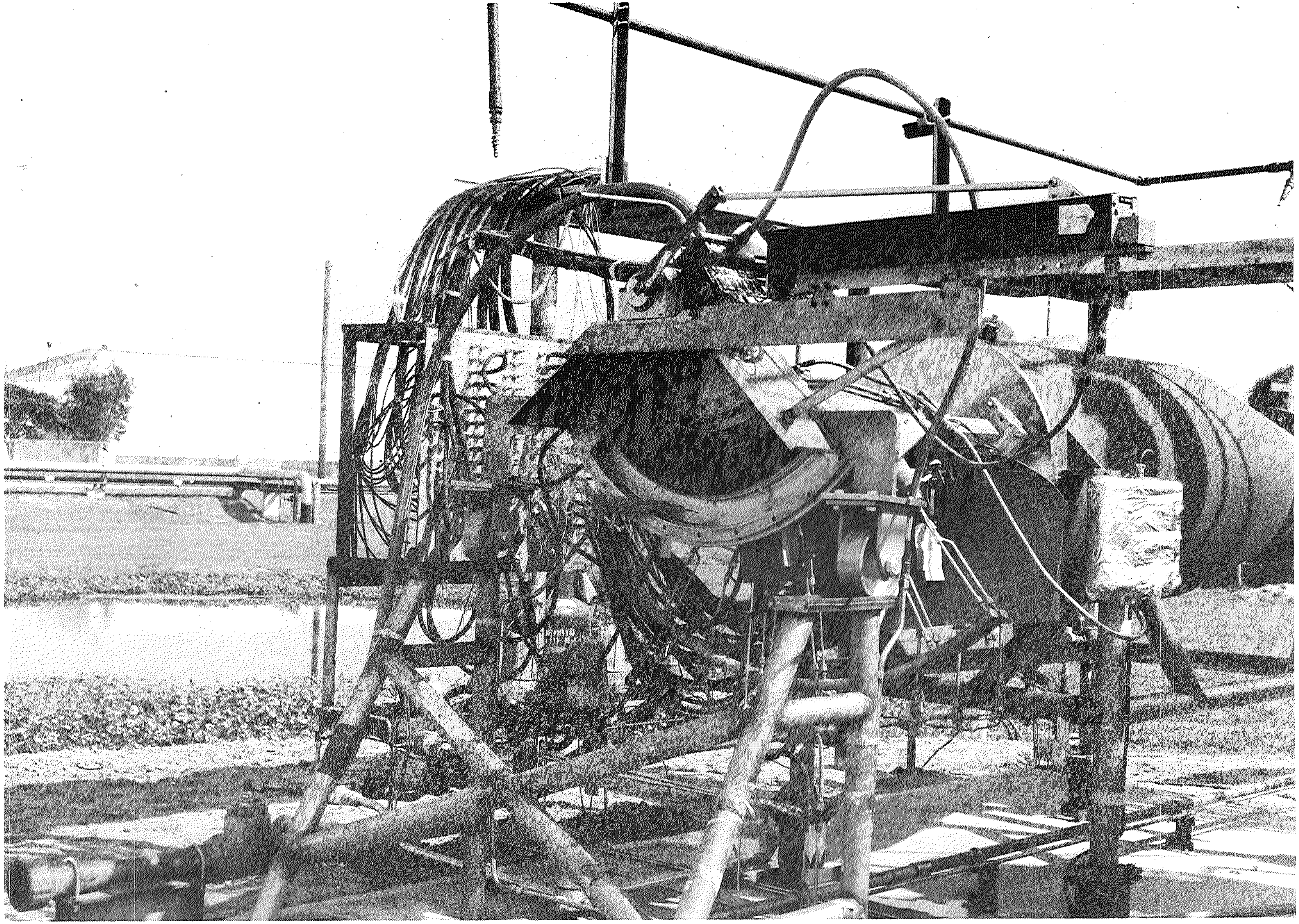

Figure 4. - Test Rig Installation at Pratt & Whitney Aircraft for 90° Sector of Twin-Ram-Induction Combustor

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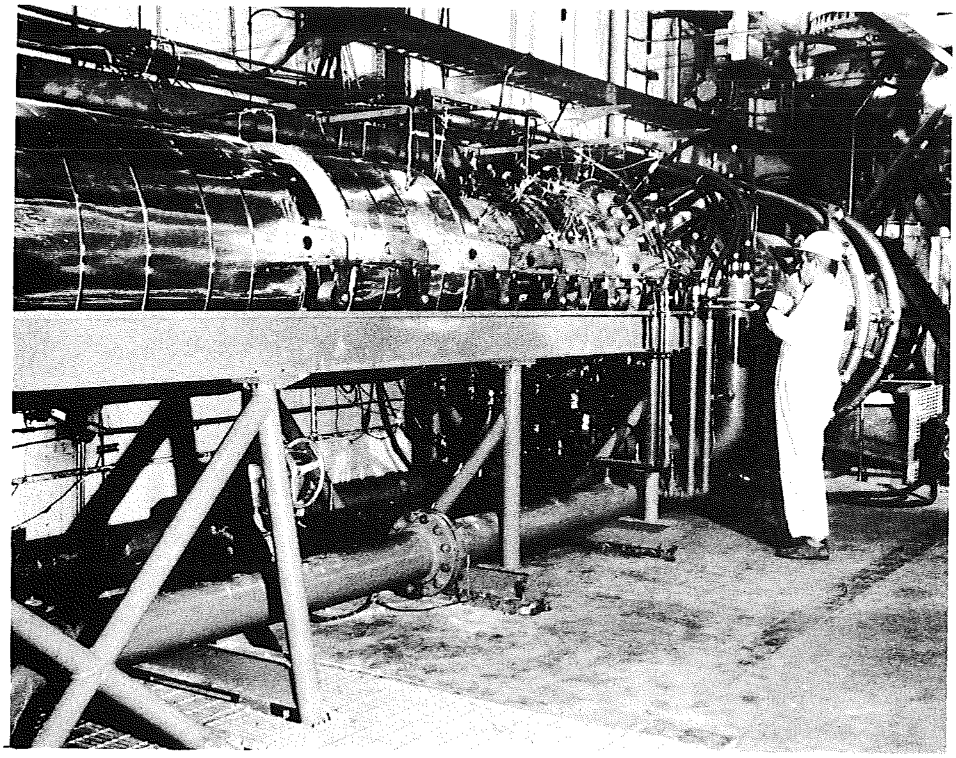

Figure 5. - Test Rig Installation
at NASA-Lewis Research Center
for Full Annular Twin Ram-Induction
Combustor

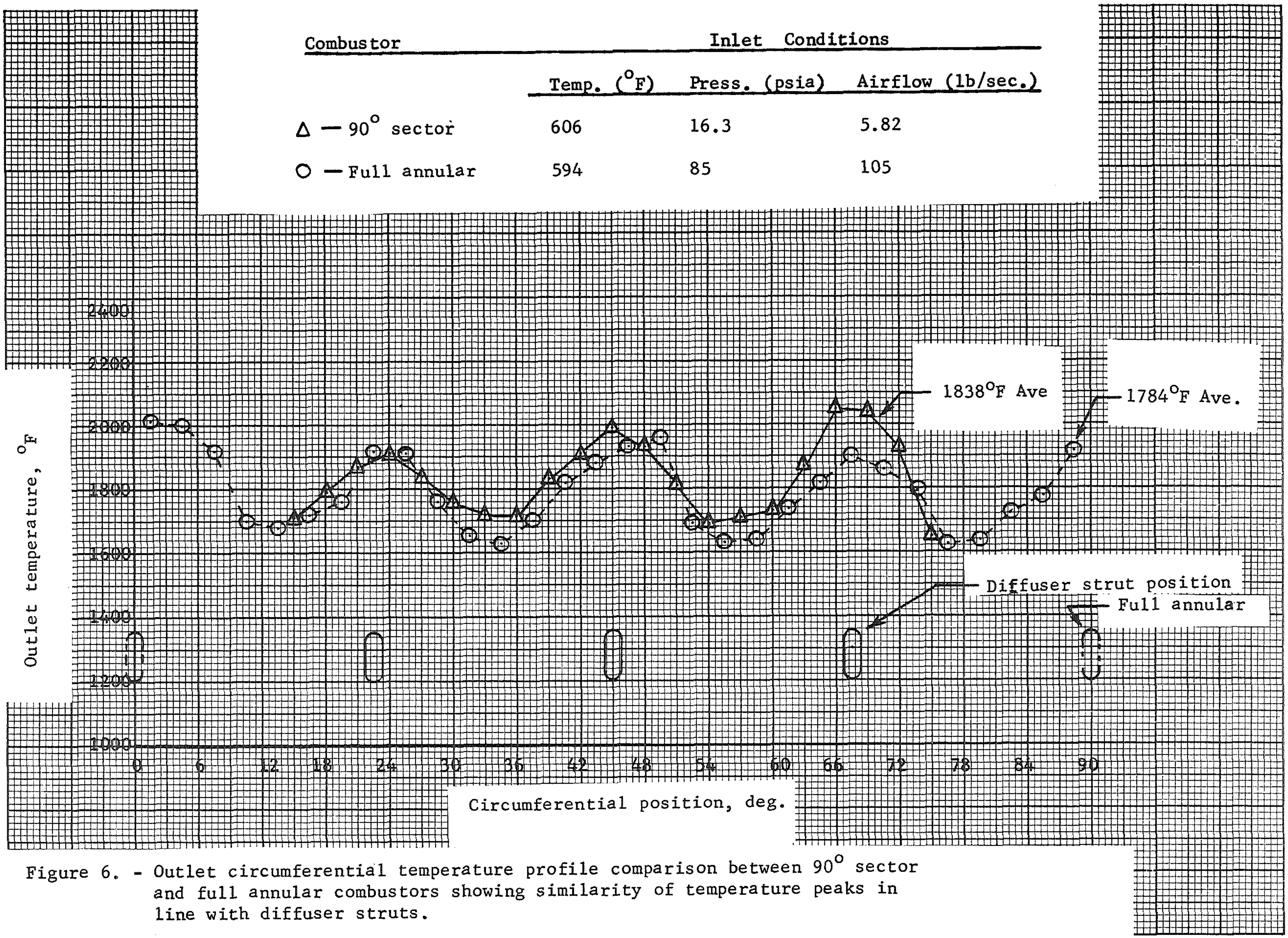

Figure 6. - Outlet circumferential temperature profile comparison between 90° sector and full annular combustors showing similarity of temperature peaks in line with diffuser struts.

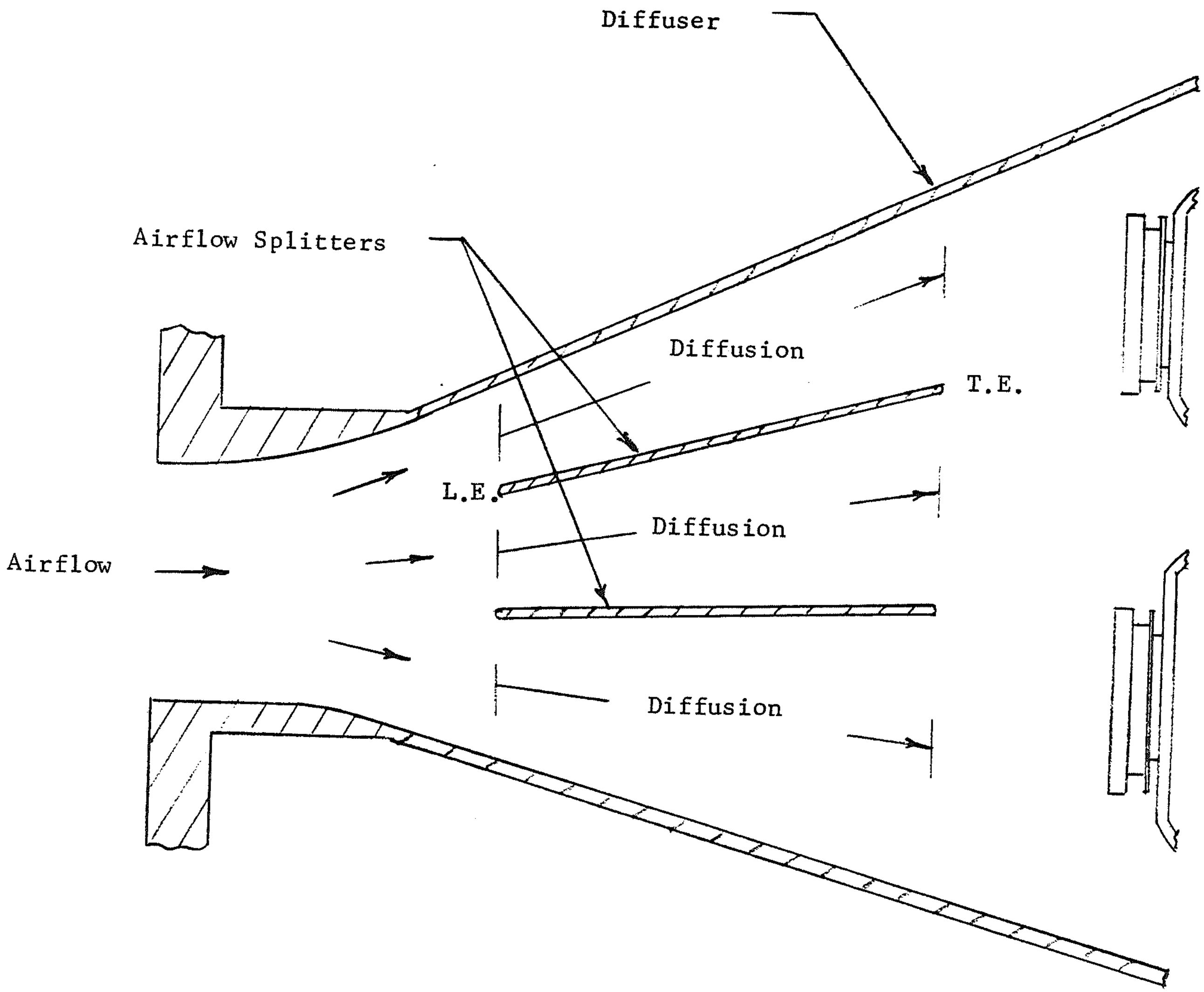

Figure 7. - Standard diffuser configuration with airflow splitters having diffusion from leading edge to trailing edge.

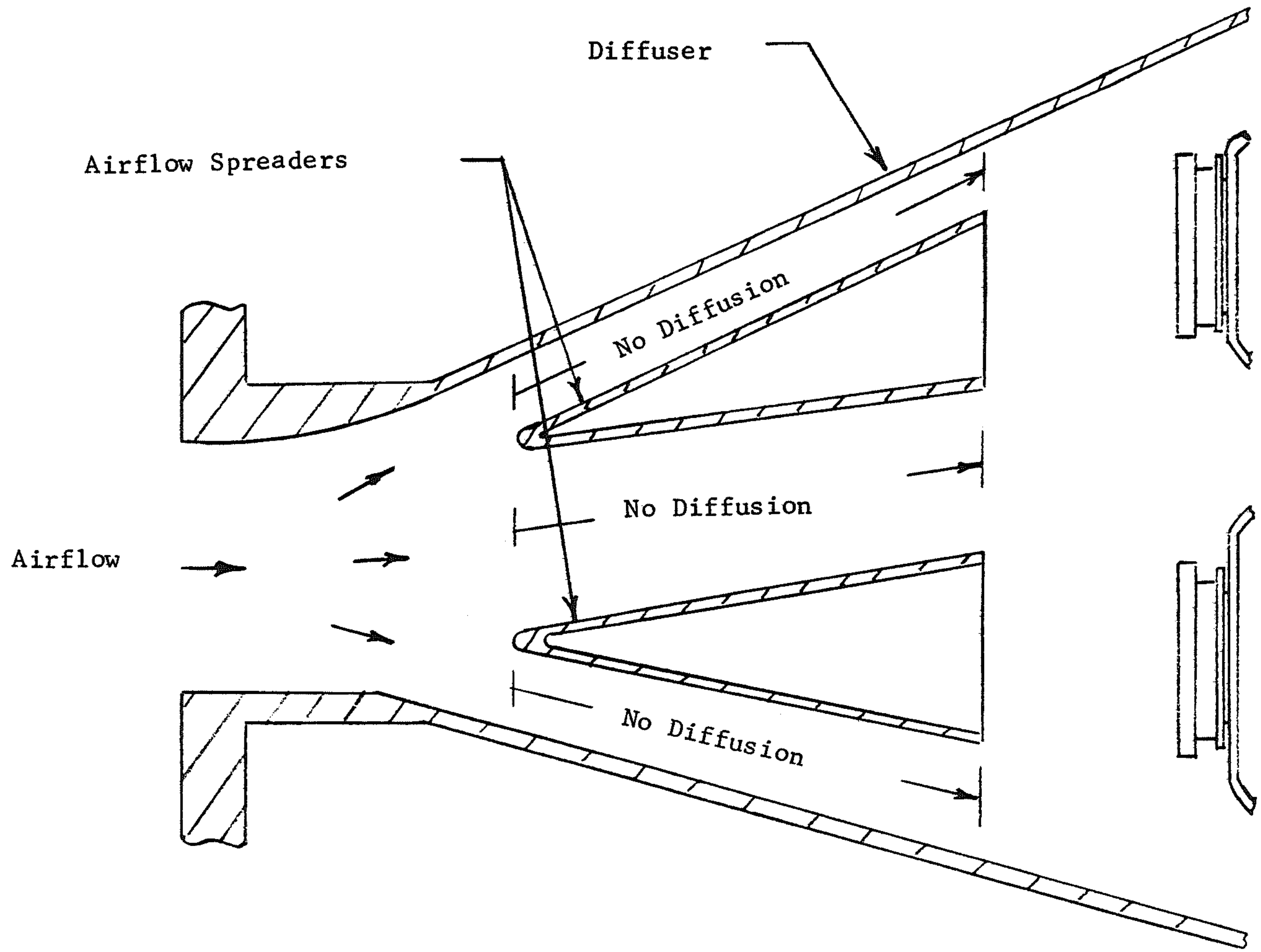

Figure 8. - Revised diffuser configuration with airflow spreaders having no diffusion from leading edge to trailing edge.

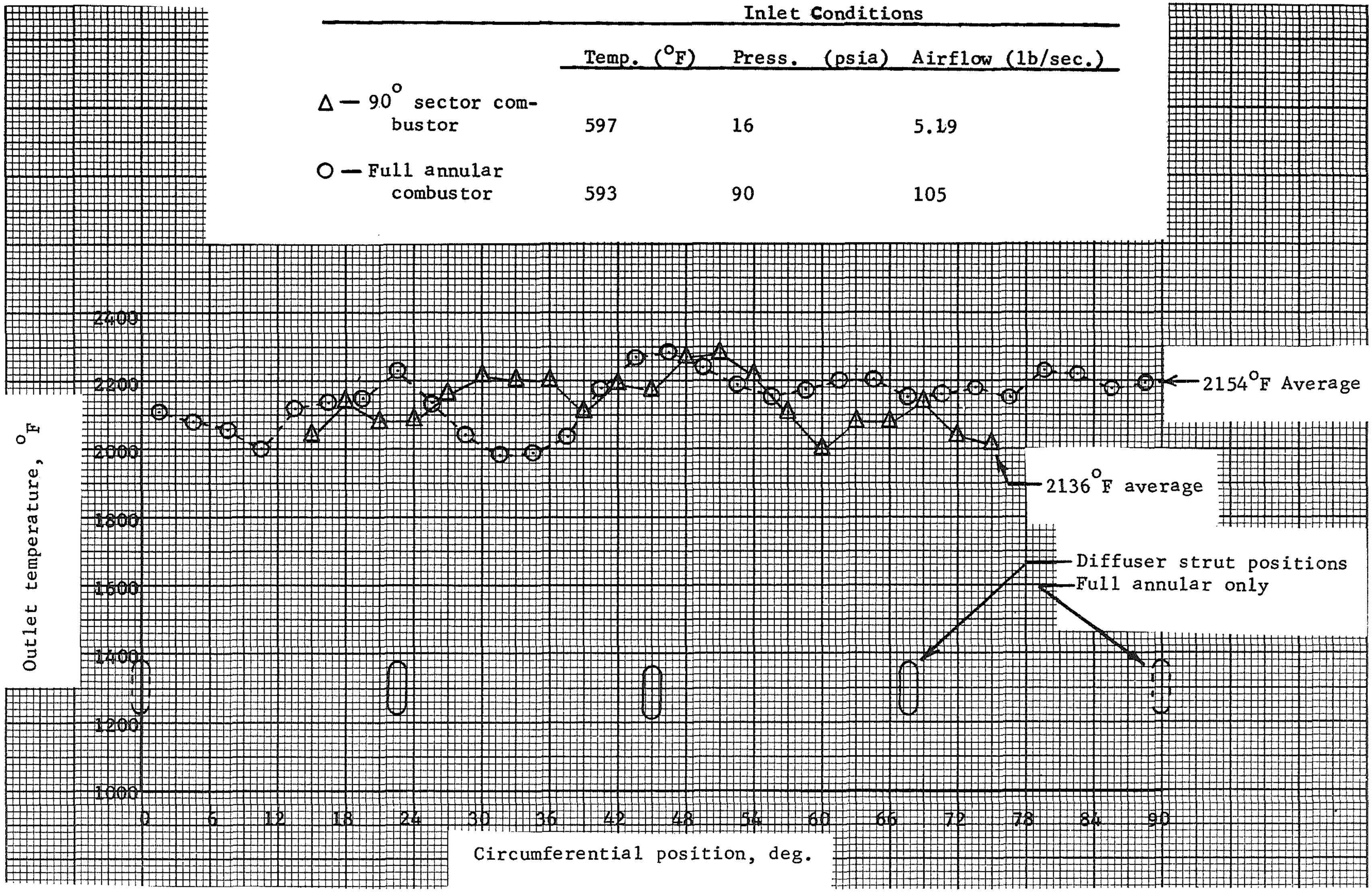

Figure 9. - Outlet circumferential temperature profile comparison between 90° sector and full annular combustors showing similarity in eliminating temperature peaks in line with diffuser struts.

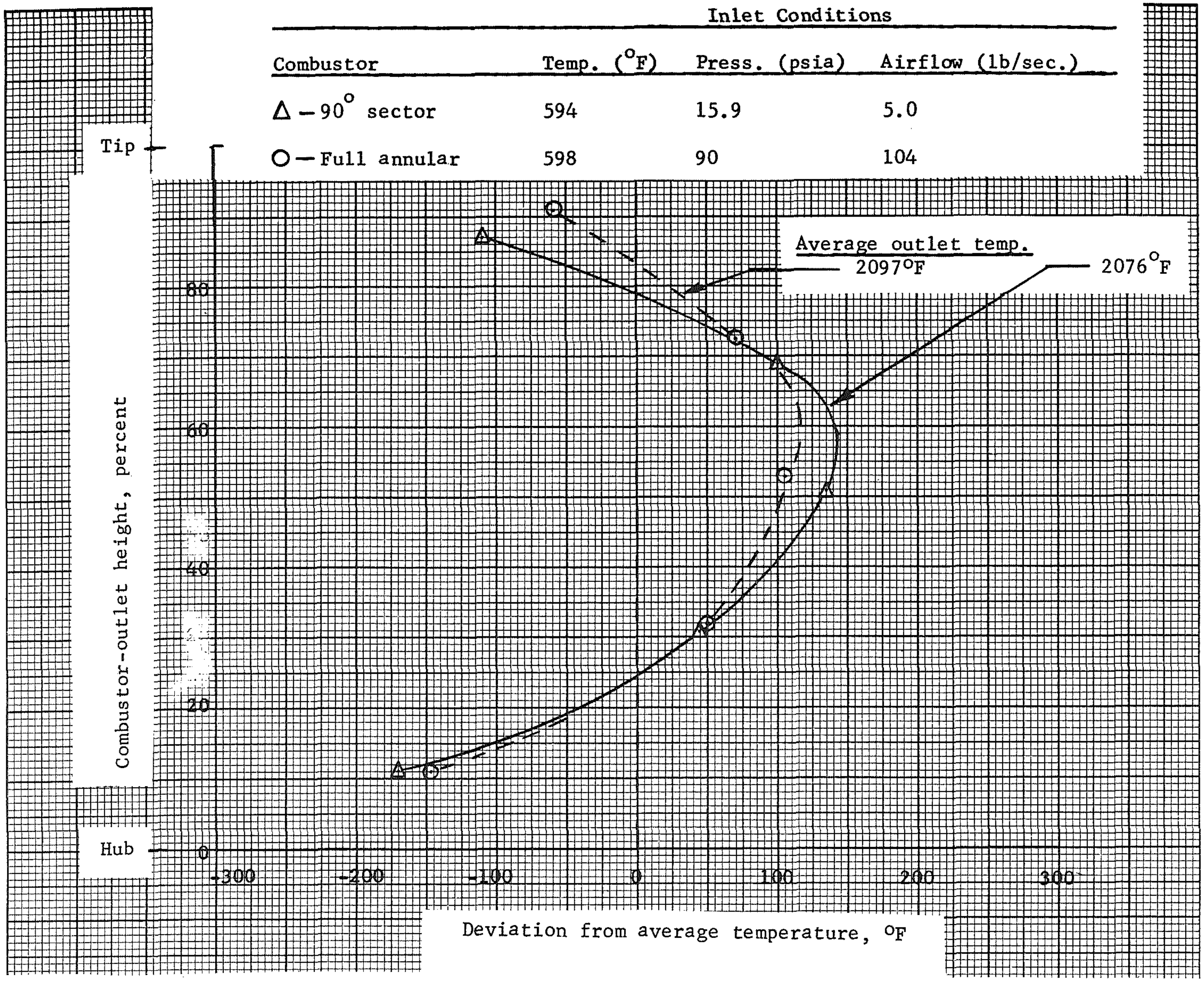

Figure 10. - Comparison of average radial exit temperature profile for 90° sector and full annular combustor.

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Combustor	Inlet Conditions: Temp. (°F)	Press. (psia)	Airflow (lb/sec.)
Δ — 90° Sector	585-616	15.3-16.3	5.0 - 6.1
O — Full annular	600-1150	90	101-105

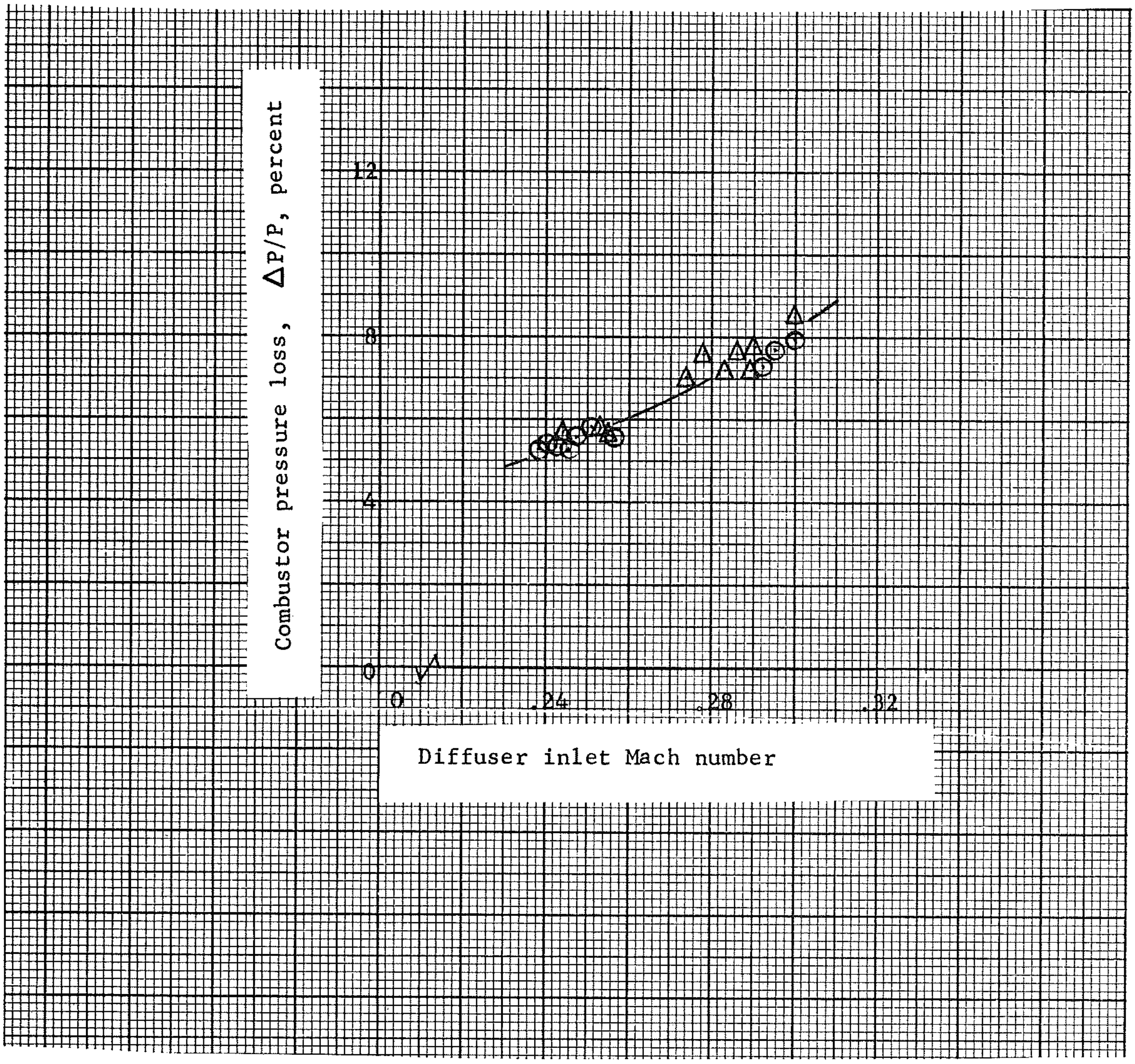

Figure 11. - Comparison of pressure loss vs. diffuser inlet Mach number for 90° sector and full annular combustor. No burning.

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	Inlet Conditions		
	Temp. (°F)	Press. (psia)	Airflow (lb/sec.)
△ — 90° sector combustor	596-625	16	4.8-5.7
○ — Full annular combustor	595	90	105

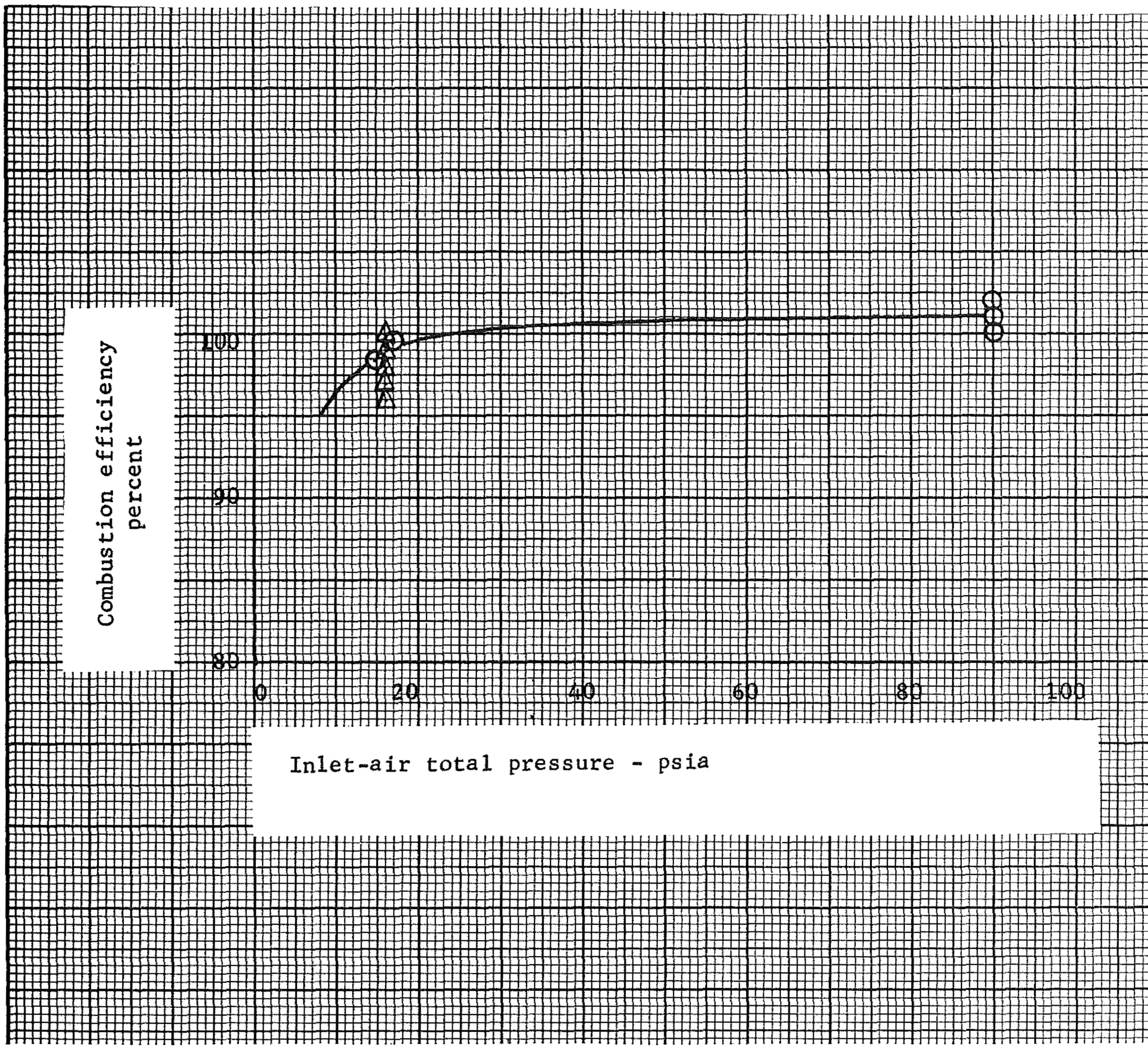

Figure 12. - Comparison of combustion efficiency vs. combustor pressure for 90° sector and full annular combustor.